Surface Wave Processes on the Continental Shelf and Beach

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LONG-TERM GOALS

Wind waves and swell dominate the hydrodynamic and sediment transport processes on many continental shelves and beaches, drive the nearshore circulation and morphology, and play an important role in remote sensing applications. Accurate wave prediction in coastal environments is a daunting challenge because waves are affected by many physical processes, including scattering by seafloor topography, wave-current interactions, nonlinear effects, wave breaking, and friction in the bottom boundary layer. Several of these processes are poorly understood and existing wave prediction models rely on parameterizations and empirical calibration to represent them. The long-term goals of this research are to obtain a better understanding of the physical processes that affect ocean surface waves in the coastal environment and develop improved wave prediction capability.

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OBJECTIVES

- Observe and predict the seafloor damping effects on ocean surface waves in sandy and muddy coastal environments.
- Advance deterministic and stochastic modeling capability for nonlinear wave evolution in coastal regions with complex seafloor topography and/or strong currents.
- Improve the representation of source terms in operational wave prediction models.
- Predict the nonlinear shoaling transformation of waves on beaches including the excitation of infragravity motions.

APPROACH

By combining theoretical advances with numerical models and field observations, we investigate the physical processes that affect ocean surface waves on continental shelves and beaches. The transformation of wave spectra is predicted with models that include the effects of refraction, scattering by wave-wave and wave-bottom interactions, and parameterizations of bottom friction, and wave breaking. Extensive field data sets were collected in ONR experiments off North Carolina (DUCK94, SandyDuck, SHOWEX), California (NCEX), and the Florida Gulf coast (SAX04/Ripples) to test these models in a range of coastal environments. Recently, we conducted additional experiments on the sandy Martha's Vineyard shelf and the muddy Louisiana shelf. Analysis techniques applied to these measurements include various inverse methods to extract directional and wavenumber properties from array cross-spectra, higher-order spectral analysis to detect nonlinear coupling, as well as standard statistical methods to determine empirical relationships between observed variables. The modeling efforts include deterministic and stochastic models that incorporate quadratic and cubic nonlinearity and wide angle diffraction effects, suitable for application to energetic wave environments with complex seafloor topography.

WORK COMPLETED

During FY09 we continued the analysis of field observations of ocean surface wave attenuation across the wide and muddy continental shelf of Western Louisiana. We deployed an extensive array of instruments (Figure 1) during February-March, 2008, that included two directional waverider buoys, six bottom tripods equipped with a pressure-velocity sensor and a current profiler, and six bottom tripods equipped with a pressure sensor. The two-dimensional array consisted of two cross-shore transects and an alongshore transect spanning a 40 by 25 km area in depths ranging from 13 to 4 m.

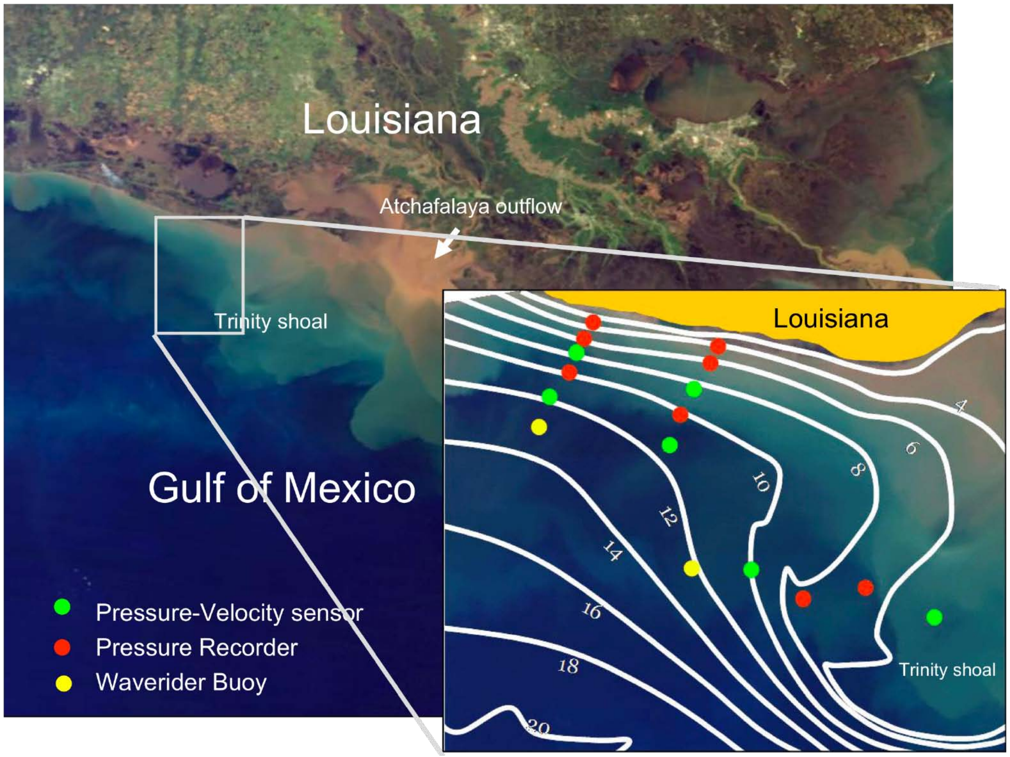

Figure 1. Field site and array plan of the Louisiana Mud Experiment. Mud deposits from the Atchafalaya River are evident in the satellite image. White lines indicate depth contours in m.

The dataset includes numerous local wind sea events with wave directions predominantly from the south (i.e. onshore propagation) but also fetch-limited wave growth conditions when the wind was directed offshore from land. To characterize the bottom, and in particular the surficial sediment properties, box cores were collected at all NPS instrument sites (Garcia-Garcia et al., 2008) and analyzed by the Johns Hopkins University (JHU) MURI team.

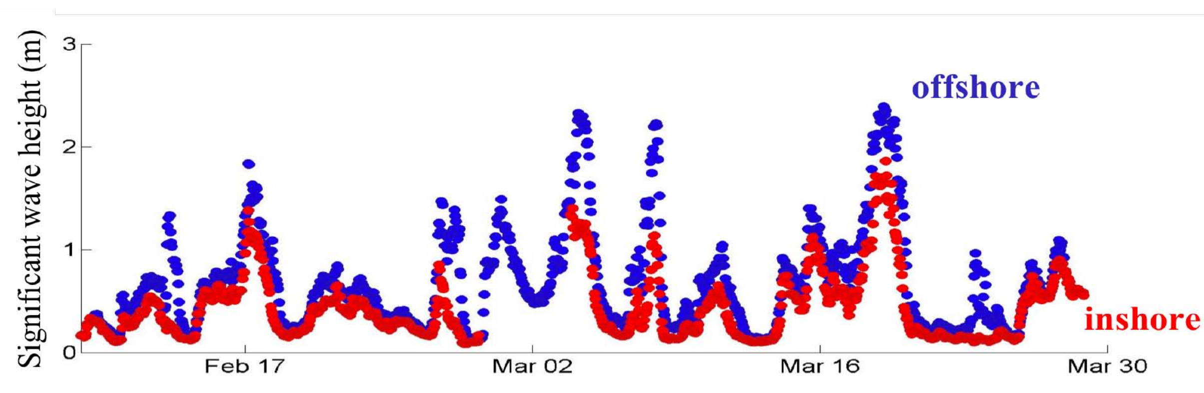

Figure 2. Wave conditions along the western transect during the Louisiana Mud Experiment. Blue and red dots indicate estimates from the offshore directional waverider buoy and the inshore bottom pressure sensor, respectively.

Preliminary analysis generally shows a consistent decay of waves from the deeper to the shallower instruments (e.g. Figures 2 and 3), similar to earlier observations (Sheremet and Stone, 2003; Elgar and Raubenheimer, 2008). The wave spectra evolution (Figure 3) shows strong decay (several orders of magnitude) of high-frequency wind sea spectral levels and weaker decay at the lower swell frequencies. These observations suggest that the dissipation is not the result of a direct wave-bottom interaction (which would affect only longer-wavelength waves), but possibly the result of heavy sediment suspension over the entire water column affecting the hydrodynamics of short wavelength waves (Sheremet and Stone, 2003). The observed decay was strongest at the shallowest site of the central transect where box cores showed fresh mud deposits (Garcia-Garcia et al., 2008) and a visibly murky sea surface was observed during the experiment cruises.

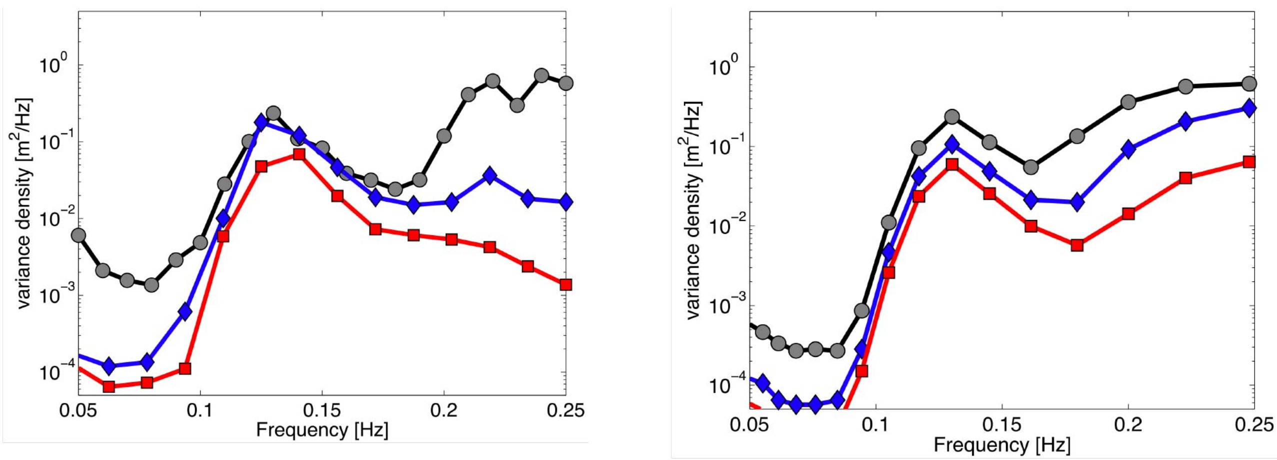

Figure 3. Observations (left panel) of wave spectral evolution across the inner Louisiana shelf on 18 February 2008 in fetch-limited (offshore wind) conditions. The data were collected on the central transect (Figure 1) with sensors located in 12m (circle markers, black), 10m (diamond markers, blue) and, 6m (square markers, red) water depth. Whereas the observed swell decay (the lower-frequency peak) agrees fairly well with model results (SWAN, right panel), the observed higher-frequency wind-sea evolution shows a dramatic suppression of wave growth in shallow water that is not predicted by the model. This comparison illustrates the critical role of wave-mud interaction processes in not only the damping of swell but also the wind-sea development in shallow water.

RESULTS

The focusing of waves on tidal currents and shoals can create local 'hot spots' of wave energy, where large, steep waves are breaking resulting in hazardous situations, in particular for small vessels. Although the linear dynamics of these phenomena are well known, very little is understood about nonlinear refraction of waves over strong shear currents, wave instabilities in such regions, and the implications for wave statistics. During FY09 we continued to develop a numerical model for the

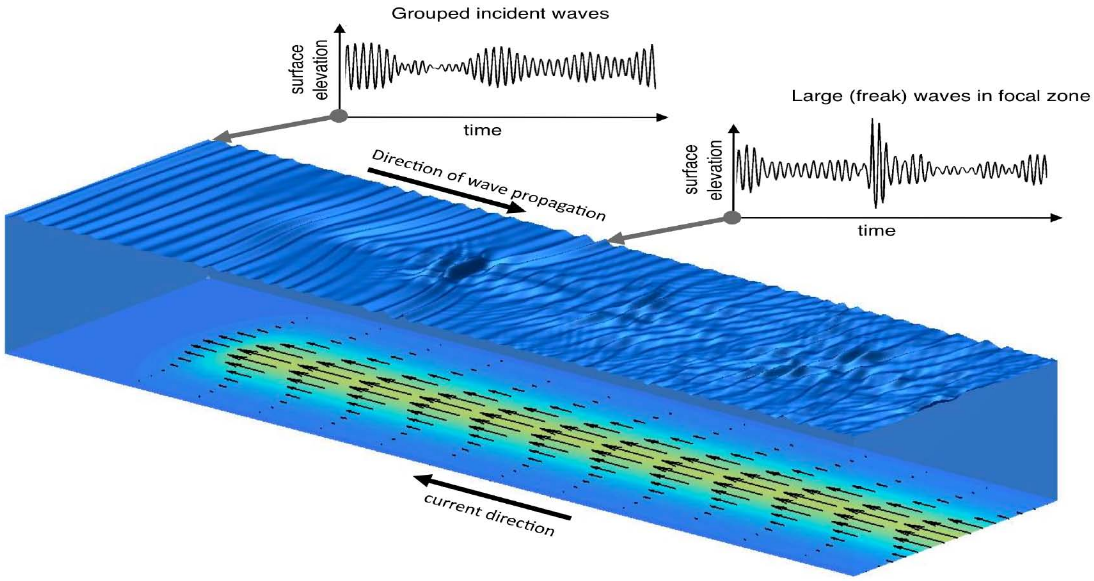

Figure 4. Waves propagating over an opposing current jet (ebb tidal flow scenario) predicted by nonlinear wave-current model [Janssen & Herbers, 2009]. Nonlinear effects in focal zone result in frequency-downshift, non- Gaussian statistics, and an enhanced likelihood of extreme (freak) waves (see time series inset).

nonlinear evolution of surface gravity waves through an inhomogeneous medium. The model describes the combined effects of wave refraction and diffraction and nonlinear wave-wave interactions through scattering source terms in an angular spectrum evolution equation [Janssen et al., 2006, 2008; Janssen & Herbers, 2009]. This general approach can accommodate realistic two-dimensional coastal features such as an isolated shoal or a tidal inlet, and the numerically efficient pseudo-spectral solution technique is well suited to Monte Carlo simulations of statistical properties.

A principal question we hope to address in this work is how nonlinear focusing over shear currents and topography affects wave statistics in refractive focal areas. Numerical simulations of random waves propagating over an idealized shoal or opposing current jet demonstrate that the abrupt variation in wave energy associated with strong refraction can indeed cause a random wave field to become unstable and develop strongly non-Gaussian statistics and freak waves [e.g. Figure 4; Janssen & Herbers, 2009].

IMPACT/APPLICATIONS

Existing spectral wave prediction models contain crude, largely untested parameterizations of seafloor damping effects. We have conducted new field experiments on sandy and muddy continental shelves that provide the much needed comprehensive data sets for improving these parameterizations. We are developing new deterministic and stochastic wave evolution models that incorporate diffraction and quadratic and cubic nonlinear effects for more accurate predictions in complex coastal environments.

REFERENCES

Elgar, S., and B. Raubenheimer, Wave dissipation by muddy seafloors. *Geophys. Res. Lett.* **35**, L07611, doi:10.1029/2008GL033245, 2008.

Janssen T. T., T. H. C. Herbers, and J. A. Battjes, Generalized evolution equations for nonlinear surface gravity waves over two-dimensional topography, *J. Fluid Mech*., **552**, 393-418, 2006.

Sheremet, A., and G. Stone, Observations of nearshore wave dissipation over muddy sea beds. *J. Geophys. Res*., **108**(C11), doi:10.1029/2003JC001885, 2003.

PUBLICATIONS

Janssen T. T., T. H. C. Herbers, and J. A. Battjes, Evolution of ocean wave statistics in shallow water: Refraction and diffraction over seafloor topography, *J. Geophys. Res*., **113**, C03024, doi:10.1029/2007JC004410, 2008. [published, refereed]

Garcia-Garcia, A., T. T. Janssen, T. H. C. Herbers, D. Alden, A. Orange, D. Orange, P. Jessen, S. Kawamoto, and P. Harvey, A geophysical baseline for the Fluid-Mud MURI site, west of Atchafalaya Bay, *Geo-Mar. Lett.*, 2008. [submitted, refereed]

Janssen T. T., and T. H. C. Herbers, Nonlinear wave statistics in a focal zone, *J. Phys. Oceanogr*., **39**(8), 1948-1964, 2009. [published, refereed]

Herbers, T. H. C, and S. J. Lentz, Observing directional properties of ocean swell with an Acoustic Doppler Current Profiler (ADCP), *J. Atmos. Oceanic Technology*. [in press, refereed]